

# KAGRA: Gravitational Wave Experiments in ASIA

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## INTRODUCTION

This year (2016) is the 100<sup>th</sup> anniversary of the publication of Einstein's paper predicting the existence of gravitational waves [1]. Even Einstein himself expected that the detection of gravitational wave would be extremely difficult. As expected, it took 100 years to detect gravitational wave directly. The first successful attempt occurred via large laser interferometry, at the Laser Interferometer Gravitational-Wave Observatory (LIGO) [2]. Early this year, the LIGO/Virgo collaboration announced the first direct detection of gravitational waves arising from a black hole binary merger [3,4]. This incredible event is very important as it is the confirmation of a new way to observe the Universe by a method other than electromagnetic waves, which means that we have advanced one step further in understanding very strong gravitational phenomena, including the early Universe. Thus, this moment could be the beginning of a very significant historical epoch for the physics and astrophysics of the future. It seems only natural to encourage young students to join this relatively new field of gravitational wave science.

There is a long history of gravitational wave detection efforts in Japan, starting with the construction of TAMA 300 [5]. The accumulation of Japanese efforts for gravitational wave detector construction led to the building of a large underground and cryogenic interferometer at Kamioka mine named Kamioka Gravitational Wave Observatory (abbreviated as KAGRA, which was previously known as the Large Cryogenic Gravitational Wave Telescope, LCGT) [6]. Fig. 1 shows one arm of the L-shape tunnels in the KAGRA site. Even though the credit for the first direct detection of gravitational waves would be given to the LIGO/Virgo collaboration, the existence of

KAGRA is important for the future advancement of this field. Therefore, in order to promote gravitational wave physics in this region, it is vital to maximize the availability of KAGRA and its facilities to scientists.



**Fig. 1:** One of the 3 km arm ducts of KAGRA.

In this article I want to introduce the Asian efforts, especially in Korea, for gravitational wave physics related to KAGRA and to LIGO/Virgo collaboration. Then I will briefly describe my own experiences participating in the initial-KAGRA (iKAGRA) operations in March and April 2016. Finally, I will comment on what I felt attending the first International Meeting on KAGRA, held at the Korea Institute of Science and Technology Information (KISTI) in Daejeon, Korea from June 24-25, 2016.

## KOREAN GRAVITATIONAL-WAVE GROUP

The active participation of Korean researchers in gravitational wave physics started in 2008, when Prof. Hyung

Mok Lee of Seoul National University organized the Korean Gravitational Wave Group (KGWG) [7]. This group is a descendent of a small, informal, group for numerical relativity supported by the Asia Pacific Center for Theoretical Physics (APCTP), which still continues to support the activities of KGWG. One of the most important activities of KGWG is organizing the Summer School on Gravitational Wave and Numerical Relativity every year. This year, the summer school was held at KISTI and the Korea Advanced Institute of Science and Technology (KAIST), in Daejeon, Korea, from June 27 to July 1, 2016. More than 70 Korean students participated [8]. The school is mainly divided into two tracks: gravitational waves and numerical relativity. Gravitational wave data analysis and numerical relativity practice were prepared with the help of the KISTI on KISTI cluster. In order to be maximally helpful for students and new researchers, the content of the school covers a range of subjects, from fundamental astrophysics, to advanced subjects like post Newtonian approximation, real gravitational wave experiment data analysis, and 3+1 formalism for numerical relativity. A survey taken after the school closes provides many ways for school to improve in the future. I believe this school will play an important role to promote research in gravitation, gravitational waves and numerical relativity/astrophysics, in Asia.

Some of members of KGWG became members of the LIGO Scientific Collaboration (LSC) in 2009. The contribution of KGWG to LSC is mainly data analysis, including detector characterization. In addition, the KISTI Global Science Experiment Data Center (GSDC) serves as a Tier 3 server of the LIGO data grid. Furthermore, some KGWG members joined the KAGRA collaboration in 2011. The collaboration of KGWG with KAGRA is not restricted to data analysis and detector characterization, but is extended to the construction of instruments, and in particular, the laser system. Active collaboration is the result of frequent discussions with the workshop, formerly known as the Korea-Japan (Japan-Korea) Workshop on KAGRA, held two times a year. This workshop retained this format until last year (2015) and the workshop now has changed into an international meeting. As such, the meeting is now called the “International Meeting on KAGRA”. The first international meeting was held this year, and I will describe it in more detail later.

### iKAGRA SHIFT

I, as a member of KGWG, joined KAGRA from 2013 as a member of the data analysis subgroup (DAS). I have

participated in an iKAGRA shift two times with my PhD student, Jeongcho Kim. The first iKAGRA shift was from March 15-31, 2016. I participated in a midnight shift on March 28-29, 2016, with Prof. Nobuyuki Kanda. It was my pleasure, to see with my eyes, the first real operation of KAGRA. Since there were many unexpected troubles, it is rather miraculous to be finished with the commissioning of the iKAGRA configuration within the scheduled time. I am impressed by hard the work of all of the members of KAGRA, which allowed us to achieve this victory. Shift operation itself was a little boring; it involved looking at various screens and recording server status for every two hours (see Fig. 2). The main difficulty was staying awake during the midnight shift.



**Fig. 2:** The control room of KAGRA.

The second iKAGRA shift was done from April 11-25, 2016. I participated in the daytime shift for this time at 16 and 17 with Prof. Yousuke Itoh. The operation of interferometer for this second iKAGRA operation was much more stable and smooth, compared to the first one. During this period, there was a big earthquake at Kumamoto which caused a shutdown of the interferometer for one day. In any case, KAGRA revealed that the end-to-end control system is working as designed and explained how one locks a long distance laser is understood. These points are important as it proves that all the key technology is ready for cryogenic bKAGRA. I could have better understanding of gravitational wave experiment with these iKAGRA shift participations.

### THE 1<sup>ST</sup> INTERNATIONAL MEETING ON KAGRA

The Korea-Japan (Japan-Korea) Workshop on KAGRA has been held since 2011, twice a year, to promote closer collaboration between the two countries for KAGRA. This series of workshops continued until June 2015, and a successful and stable collaboration channel between



**Fig. 3:** The first international meeting on KAGRA at KISTI.

Korea and Japan was established. The format of the workshop was changed and enlarged in order to include more countries, especially those in Asia. Consequently, the name of the workshop changed to the “International Meeting on KAGRA”. The first International Meeting on KAGRA was held in KISTI, Daejeon from June 24-25, 2016.

As this was an international meeting, there were participants from additional countries and regions such as China, Hong Kong, Taiwan, Australia and India. Dr. Philwoo Lee (KISTI), Prof. Hyung Mok Lee (SNU) and Takaaki Kajita (ICRR) opened the meeting. The meeting started with a status report of KAGRA, including the lessons from the successful iKAGRA operation. During the meeting, there were discussions regarding the various

possibilities for new tasks in gravitational wave physics that could be accomplished with KAGRA in the future.

I felt that this meeting was really the beginning of international collaboration on gravitational waves in Asia. Furthermore, there were numerous talks about expanding and inviting participants from many other Asian countries in order to promote and utilize KAGRA’s contribution to gravitational wave physics. The next International Meeting on KAGRA will be held at Beijing Normal University, Beijing, China from November 11-12, 2016. I encourage all of you to participate in this meeting.

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**Hyung Won Lee** has been a professor in the Department of Computer Simulation at Inje University, Korea, since 1993. After receiving his PhD from Sogang University in supergravity, he worked at the University of Rome. From 2010, he has been working as a member of the Korean Gravitational Wave Group (KGWG). Since 2013, he has been collaborating with KAGRA and became a senior LIGO Scientific Collaboration (LSC) member in 2016. His research fields are cosmology and general relativity, especially in relation to gravitational wave experiments. He is an expert in developing scientific programs and is now developing a parameter estimation pipeline for KAGRA.